Vocabulary

aquifer	endangered	infrared energy	natural selection
artificial selection	estuary	irrigate	La Niña
carbon cycle	extinction	isotope	El Niño
deforestation	gene pool	long-wave radiation	radiant energy
ecosystem	greenhouse effect	marsh	

The Greenhouse Effect

As early as the 19th century people recognized that carbon dioxide (CO_2) in the atmosphere contributed to the greenhouse effect that helps warm our planet (see Figure 4-3-1).

The greenhouse effect explains why heat builds up on a sunny day inside an enclosed space like a greenhouse or a parked car. Radiant energy from the sun passes easily through the glass windows of the enclosure and is absorbed by the materials inside, causing them to heat up. When these materials get hot, their molecules begin to vibrate and emit infrared radiation, the radiation we experience as heat. This radiation is absorbed by the glass, unlike the visible sunlight, and the heat is trapped.

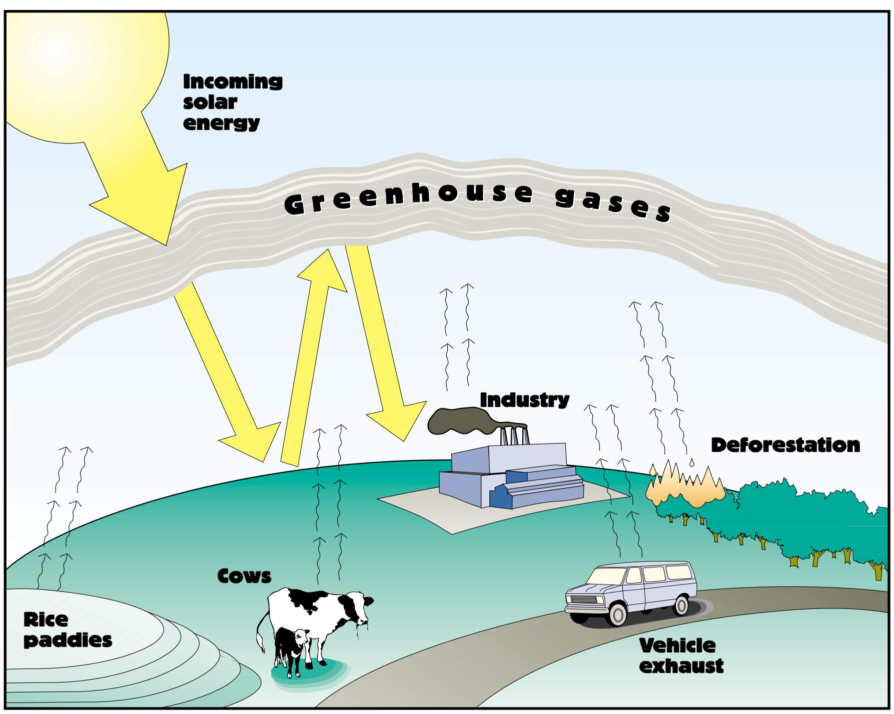


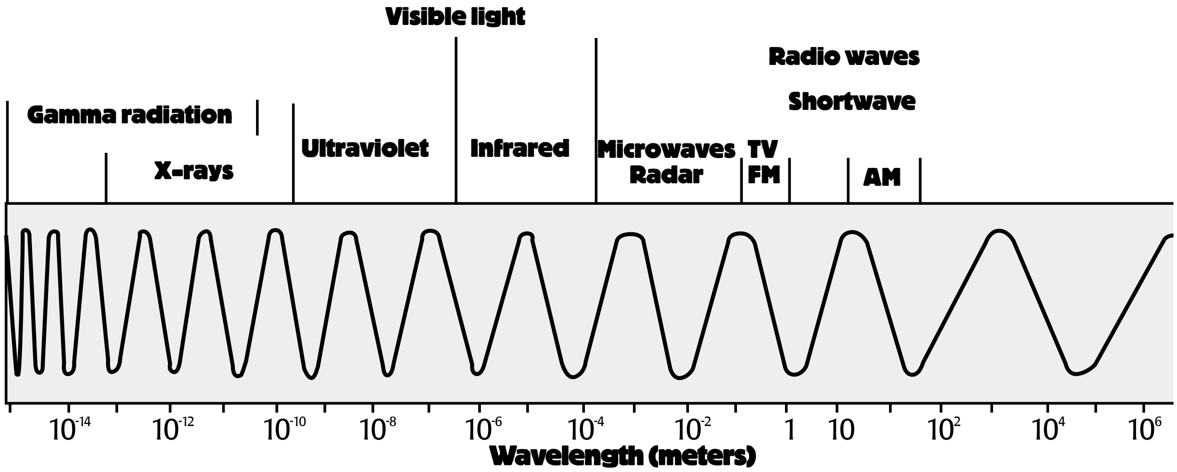
Figure 4-3-1 Greenhouse gases

The earth is like a greenhouse. Solar radiation passes easily through the atmosphere and strikes the surface, where the radiant energy is absorbed and changed into heat by water, soil and other materials. These materials then re-radiate longer-wavelength infrared energy (heat) back out towards space. But not all the heat escapes. Some heat is trapped and re-radiated by CO_2 and other "greenhouse gases" in the atmosphere, thus warming the earth.

Why do greenhouse gases absorb heat while other atmospheric gases, such as oxygen and nitrogen, do not? The answer lies in their chemical makeup. Only those molecules containing bonds between different atoms (e.g. carbon and oxygen) can absorb and emit infrared radiation. This is why nitrogen (N_2) and oxygen (O_2) are not greenhouse gases. Heat-absorbing greenhouse gases include carbon dioxide, methane (CH_4), chlorofluorocarbons (CFCs) and nitrous oxide (N_2O). Water vapor is also considered a greenhouse gas.

Greenhouse gases enter the atmosphere from both nature and human activities. Carbon dioxide, for example, is released from animals' exhalations and from the burning of fuels that contain carbon, such as wood, coal, natural gas and gasoline. Water vapor is produced from evaporation and combustion. Methane forms from decomposing organic matter and from cattle, wetlands, rice fields and landfills. Chlorofluorocarbons are industrial chemicals used in some aerosols, refrigerants and manufacturing processes. Nitrous oxide is formed inside internal-combustion engines and by natural biological processes in soil.

Figure 4-3-2 The Electromagnetic spectrum



The electromagnetic spectrum includes radio, infrared, visible light, ultraviolet, x-rays, and gamma rays.

Solar radiation, a term used to describe all electromagnetic radiation emitted by the sun including visible light, passes through the atmosphere, is absorbed, and re-radiated back out to space as infrared (heat) waves.

The Carbon Cycle

Greenhouse gases cycle in and out of the atmosphere. Water vapor condenses and precipitates as rain or snow. Carbon dioxide moves in and out of the atmosphere as part of the carbon cycle.

The carbon cycle involves plants and animals. Plants need carbon dioxide to grow. They take in carbon dioxide from the air and convert it by photosynthesis to carbohydrates such as cellulose, the main material in plants' cell walls. Animals eat the plants and release carbon dioxide into the air by their exhalations and decay (Figure 4-3-3).

The carbon cycle is global in scope. It affects the land, the sea and the air. Overall, about as much carbon is absorbed as is produced. However, many scientists are concerned that human activities like the burning of fossil fuels and forests are increasing atmospheric carbon dioxide to levels that the plants and oceans cannot reabsorb.

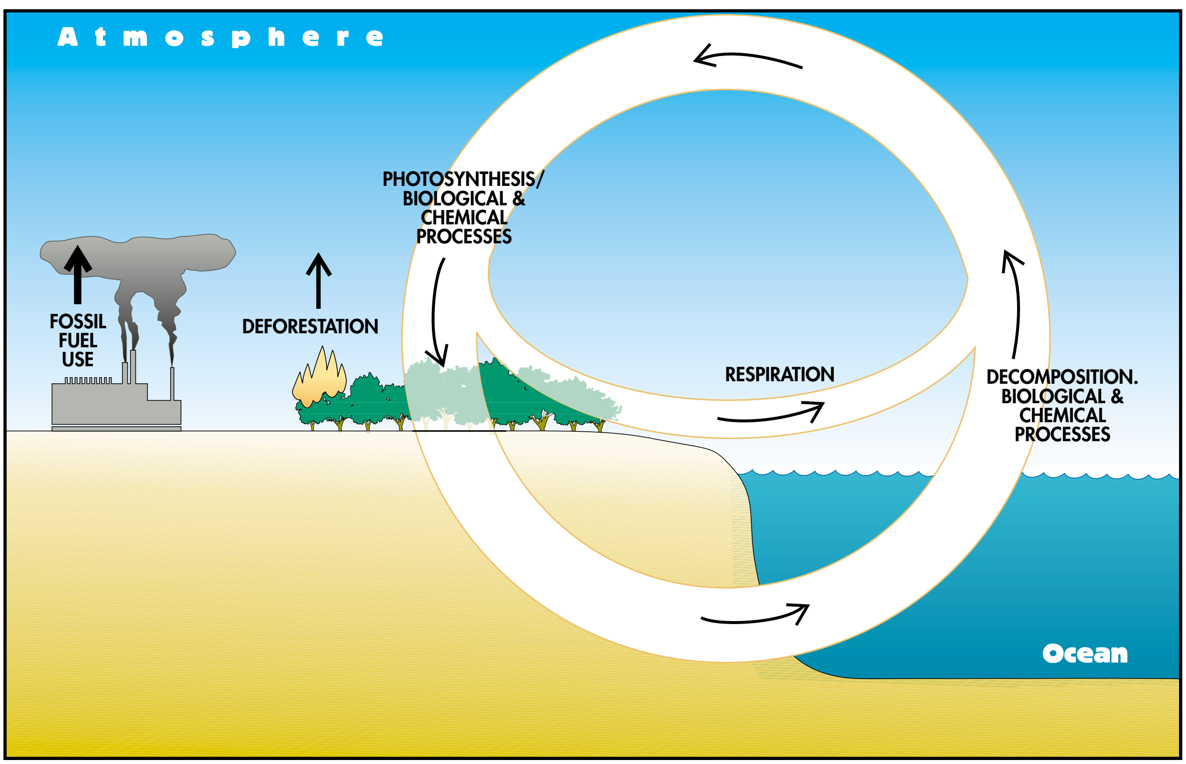


Figure 4-3-3
The carbon cycle

The Big Picture: Milankovic Cycles

Greenhouse gases are only one factor in global climate change. Natural, long-term causes of global climate change can be explained by changes in the relative positions of the earth and the sun called Milankovic cycles.

Orbital flexing. The earth's orbit is not always the same shape. The orbit stretches from its most round to its most elliptical and back again every 90,000-100,000 years. Orbital flexing varies the distance from the earth to the sun by more than 11 million miles.

This variation helps determine how much extra solar energy the earth receives at perihelion, the point in earth's orbit closest to the sun, compared to the amount received at aphelion, the point farthest from the sun. When its orbit is most elliptical, earth receives about 20 to 30 percent more solar radiation at perihelion than at aphelion. The difference observed today is 6 percent (Figure 4-3-4).

Tilting of earth's axis. The earth rotates about its axis, an imaginary line that passes through the north and south poles. The axis is tilted at an angle to the plane of earth's orbit. The tilt now is about 23.5 degrees. But over a 41,000-year cycle the amount of tilt changes from a minimum of 22.1 degrees to a maximum of 24.5 degrees and back again.

Axial tilting is the key to seasonal differences in climate. If the earth's axis of rotation were perpendicular to the plane of its orbit, there would be no seasons. Each point on earth's surface would receive the same amount of solar energy every day, regardless of where

FYI

Theory and Evidence

Milutin Milankovic, a Yugoslavian professor of mathematics, put forth his astronomical theory of long-term global climate change in 1920. Since that time, evidence has accumulated that Milankovic was right.

In 1976 a team led by Nicholas Shackleton of the University of Cambridge proved that Milankovic's astronomical cycles closely matched Earth's glacial cycles. The scientists measured the ratio of two oxygen isotopes, O_{18} and O_{16}, in marine fossils. They knew that organisms from cold water contain a higher proportion of the heavier isotope, O_{18}. Core samples for the Indian Ocean and the Antarctic yielded firm evidence of a 100,000-year cycle.

Two American researchers from the same international consortium ran more detailed analyses of core samples to determine their chemical content. Statistical analysis of the results provided evidence of the 41,000-year and 23,000-year climatic cycles predicted by Milankovic.

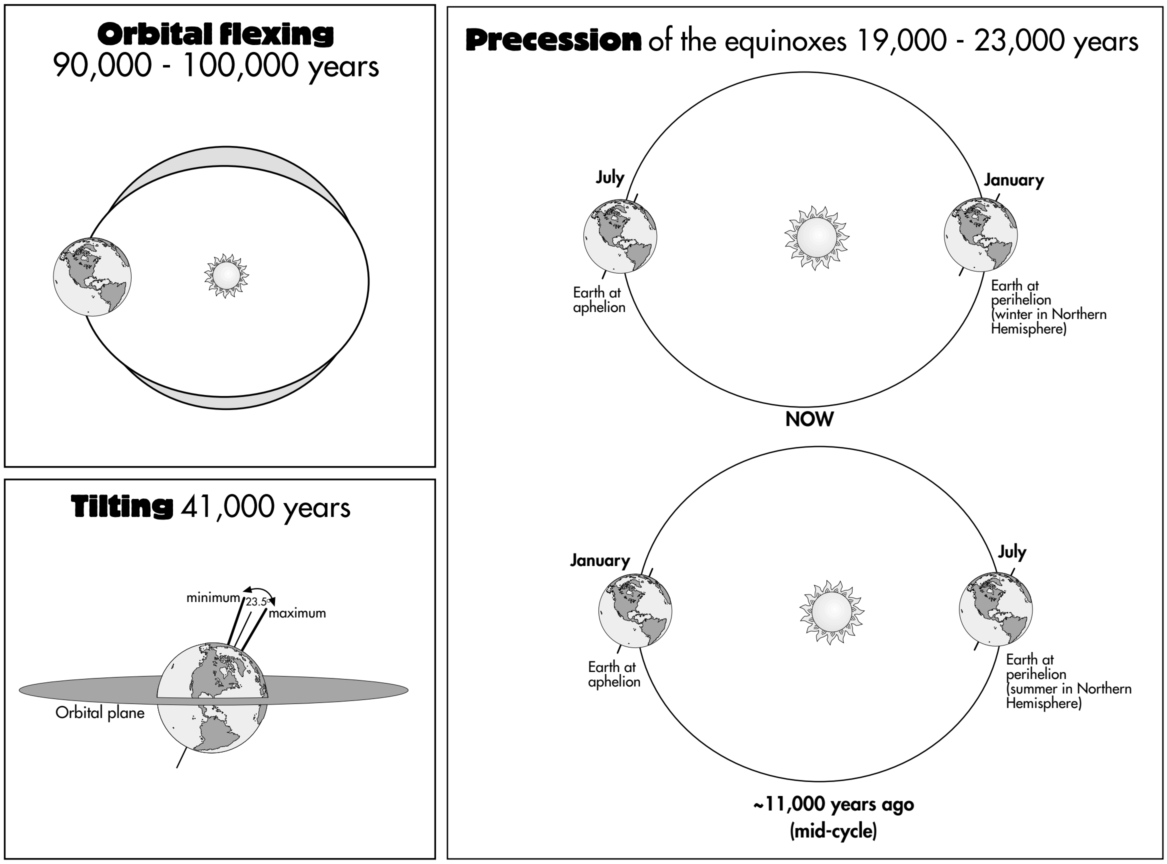


Figure 4-3-4 Milankovich cycles

the planet was in its orbit. But because the axis tilts, the amount of solar energy received differs from season to season. Each side of the earth takes its turn facing more towards the sun (summer) and then half a year later when the earth is at the opposite side of its orbit, away from the sun (winter).

Since axial tilt causes seasons, it follows that the greater the tilt, the greater the seasonal variation in climate. Winters are coldest and summers are warmest when earth's axis tilts the most.

Precession. The earth's orbit around the sun is not a perfect circle, so the earth is not always the same distance from the sun. When the earth is closest to the sun (perihelion), it receives more solar energy than when it is farthest from the sun (aphelion).

Three major periodic variations lead to dramatic changes in earth's climate

- The earth's distance to the sun
- The tilt of the earth's rotation axis
- The orientation of earth's axis

Perihelion does not occur at exactly the same time every year. As the sun and moon's gravity pulls on the earth, its rotation axis wobbles like that of a spinning toy top. Since the tilt of the axis determines when the seasons of the year occur, this wobble slowly changes the date of perihelion, moving it back about one full day every 58 years, or one complete cycle every 21,000 years.

Currently perihelion occurs in early January, during winter in the Northern Hemisphere. 11,000 years ago perihelion occurred—and earth received its maximum amount of solar radiation—in July, during the Northern Hemisphere's summer.

Because the three cycles have different periods, they can produce a wide variety of climate changes, depending on how they interact. For example, northern winter is currently moderated because it occurs near perihelion. We can expect more severe winters in about 13,000 years when winter occurs near apehelion.

Past Climate Changes

Earth's climate has experienced big changes in the past. For example, during the Mesozoic era (the era of the dinosaurs) the mean global temperature may have been as much as 6°-8°C (11°-14°F) warmer than it is today. Fossils of large trees, warm-water mollusks and cold-blooded reptiles have been found in what today are arctic climates.

The end of the dinosaurs and the beginning of the Cenozoic era 65 million years ago brought a cooling trend. At the height of the ensuing ice age 15,000-23,000 years ago, the world was about 4°C (7°F) cooler than it is now. Sea level dropped as polar icecaps grew, and early humans were able to migrate across the Bering Strait from Asia to North America.

FYI

How do we know what was in the air 100,000 years ago?

One way is to drill into glaciers and analyze the ice. Long cylinders of glacial ice, called "core samples," contain carbon dioxide, methane and other gases that were dissolved in the ancient water when it froze. Laboratory analysis of these dissolved gases allows researchers to estimate how much of each gas was in the atmosphere at that time. Researchers also estimate average temperatures by analyzing the amounts of certain hydrogen isotopes in core samples of glacial ice.

Claude Lorius and his colleagues at the Laboratory of Glaciology and Geophysics of the Environment near Grenoble, France, reconstructed a 160,000-year record of atmospheric gases and temperature by studying 2,000 meters of ice cores recovered from Antarctica. The ice record showed a strong relationship between climate and chemical composition of the atmosphere and proved that CO_2 in the atmosphere has increased since the beginning of the Industrial Revolution.

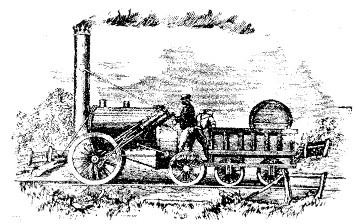
Climate Change and the Environment

Changes in temperature and precipitation affect natural ecosystems, sea level, agricultural production and human health.

An ecosystem is a system of relationships between organisms and their environment and among organisms themselves. Major climatic changes require plants and animals to adapt to the new conditions or die out.

Organisms adapt by natural or artificial selection. Natural selection occurs when organisms survive and transmit their genetic characteristics to the next generation without human intervention. Artificial selection occurs when human activity or choices force an organism to adapt or die out. The Incas' cultivation of potatoes and corn that could live at high altitude in the Andes mountains is an example of forced adaptation. Another example is the introduction of kudzu, an ornamental vine planted in the U.S. South in the 1930's to control erosion. Since that time kudzu has spread uncontrollably up the East Coast, disrupting ecosystems in its path.

Species that die faster than they can reproduce under changed environmental conditions become endangered or extinct. Extinction shrinks the gene pool—the reservoir of genetic resources that organisms draw upon to adapt to changed environments by natural or artificial selection. Following the extinctions that brought the Cretaceous period to a close 65 million years ago, 5 to 10 million years passed before diversity in the gene pool was restored to previous levels.



The Industrial Revolution began in the 1750's and was a time of transformation from hand tools to mass production of machine-manufactured goods. Production swelled, but so did CO_2 levels in the atmosphere.

Figure 4-3-5 Industrial Revolution

Global Warming Concerns

Many scientists are concerned that increased emissions of greenhouse gases and global warming could disrupt today's ecosystems. Global warming could cause ocean water to expand and glacial runoff to swell the oceans. A predicted rise in sea level of 2 mm per year could reshape coastlines and endanger coastal cities and habitats. A one-meter rise in sea level over the next century would bring the ocean to heights unprecedented in the history of civilization. Such a rise could increase storm damage; increase the salinity of marshes, estuaries, and aquifers; submerge thousands of square miles of coastal land; release wastes stored within the 100-year flood plain; and threaten drinking-water supplies.

Crop Patterns and Vegetation

Global warming could also shift temperature zones, rainfall patterns and agricultural belts. The local effects of this shifting could be either beneficial or harmful.

Temperature extremes and rainfall patterns largely determine which plants can grow in a given location. As temperature increases, forests that flourished in one area would no longer be able to survive. For instance, sweet gum trees, now found typically in southern forests, grew in Canada 100,000 years ago. Similarly, global warming could reduce soil moisture to the point where East Texas' piney woods, an important forest resource, could be reduced in size or shift towards wetter areas.

Warming of the earth and reduced precipitation would increase evaporation, reduce runoff into groundwater systems and increase the need to irrigate crops. Water supplies could be compromised. Production of crops such as wheat and corn in the Middle West and Great Plains could decrease, while other areas to the north could benefit. In general, vegetation is expected to shift 60 miles north for each 10ºC increase in temperature.

Public Health Concerns

A warming trend is also cause for concern about public health. One way that long-lasting extremes and wide fluctuations in weather spread disease is by disturbing relationships between prey and predator. For example, under warmer conditions predators of mosquitoes and rodents may fail to flourish, thus increasing populations of these disease-carrying organisms. The incidence of malaria, encephalitis and other mosquito- or rodent-borne diseases may increase when the climate warms.

Predicting Global Climate Change

Models that attempt to predict global climate change make assumptions about increasing fossil-fuel use and rates at which alternative energy sources and conservation measures are adopted. Typical projections assume that fossil-fuel use will continue to increase at a fairly constant rate, between 0.2 and 0.5 percent (3 billion metric tons) a year. These projections take into account increasing population, conservation measures and increasing use of alternative energy sources.

Scientists cannot yet predict how changes in one global system will affect others. For example, as water vapor increases, the planet warms up, glaciers melt, and less energy is reflected back into space. The reflective properties of land versus those of ice then become factors in the equation to determine the overall effects of global warming.

Mathematical models reveal that as greenhouse gases increase in the atmosphere, energy is absorbed proportionately. For instance, doubling the amount of CO_2 in the atmosphere would increase global average temperatures by an estimated 1.2ºC (2.2ºF). Doubling all known greenhouse gases would increase global average temperatures by an estimated 4ºC (7ºF). Some current models show concentrations of greenhouse gases doubling preindustrial concentrations by the middle of the present century.

El Niño and La Niña

To gain insight into global warming, scientists have been studying El Niño, an oceanic phenomenon that occurs every four to 12 years around Christmas ("El Niño" means "the Christ child" in Spanish). During El Niño periods, the South Pacific ocean off Peru becomes unusually warm and stays that way for several months before either returning to normal or becoming unusually cold (La Niña). Since 1976 meteorologists have reported increases in the strength and frequency of El Niño.

El Niño produces many of the same changes in weather patterns predicted by models of longer-term warming trends. These models predict that as the earth warms up, occurrences of El Niño will increase. This proved accurate during the 1990s, when the weather every year was influenced by El Niño or La Niña extremes.

A 100-year-old question

In 1896 a Swedish chemist, Svante Arrhenius, posed the question that underlies current theories of global climate change.

Arrhenius' question was: "Is the mean temperature of the ground influenced by heat-absorbing gases in the atmosphere?"

Using mathematical equations, Arrhenius determined that as carbon dioxide levels rose or fell, the earth's temperature would rise or fall in turn. Scientists dismissed Arrhenius' work until about 1960, when the buildup of carbon dioxide in the atmosphere began to cause concern among some scientists. Arrhenius' climate model was found to be remarkably consistent with modern computer simulations.

Arrhenius was not a climatologist. He wrote his Ph.D. thesis on the chemical theory of electrolytes. The thesis was not received well, and he barely passed. After graduating he took a position as a chemistry teacher at a high school in Stockholm. Confident in his research on electrolytes, he continued to send his papers to chemists throughout Europe. Arrhenius' outstanding work finally gained recognition, and he was awarded the Nobel Prize for chemistry in 1903.

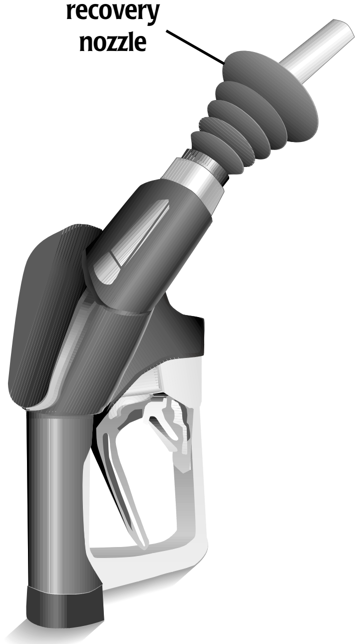


Figure 4-3-6 *Vapor recovery nozzles cut down on vapor release when you put gas in your car.*

Policy Alternatives

One approach to global climate change is to simply let it happen, judging that as the need for change presents itself, society will adapt and economies will adjust. Increasingly, however, policy makers are seeking to reduce the buildup of greenhouse gases by using alternative energy sources, encouraging the use of natural gas, propane and other fuels that emit less carbon dioxide, reducing deforestation, and restoring forests and wetlands. Supporters of this approach say that even if global-warming predictions are overstated, the choice to reduce pollution could never be wrong.

Other air-quality regulations affect greenhouse-gas emissions. For example, the federal Clean Air Act authorizes the U.S. Environmental Protection Agency to identify and regulate air pollutants. Some EPA-regulated pollutants, like oxides of nitrogen, are greenhouse gases as well as smog-forming compounds. Similarly, 148 nations have signed the Montreal Protocol limiting production of chlorofluorocarbons. In addition to being greenhouse gases, chlorofluorocarbons deplete the protective ozone layer in the upper atmosphere.

Greenhouse-Gas Emissions from Transportation Fuels

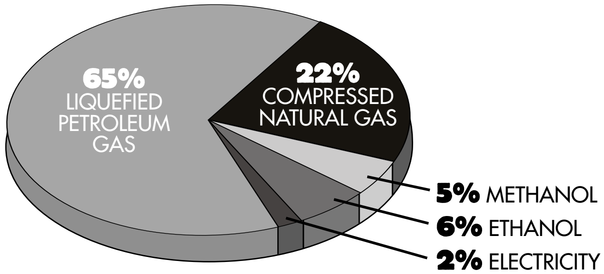


Figure 4-3-7 *Number of alternative fuel vehicles in use in the US in 1999.*

Alternative fuels can help reduce emissions of greenhouse gases. Mark Delucchi of the Institute of Transportation Studies in Davis, California, studied the amount of greenhouse gases emitted by a number of fuels, including reformulated gasoline, diesel fuel, liquid propane gas (LPG), ethanol, methanol, compressed natural gas (CNG) and electricity. His analysis included emissions during the entire process of producing, distributing and consuming each fuel.

Delucchi concluded that as far as greenhouse emissions are concerned, LPG is the best fossil-fuel alternative. Compared to gasoline, LPG reduces greenhouse emissions by up to 40 percent. The reasons for this difference include LPG's lower carbon content and low carbon monoxide emissions.

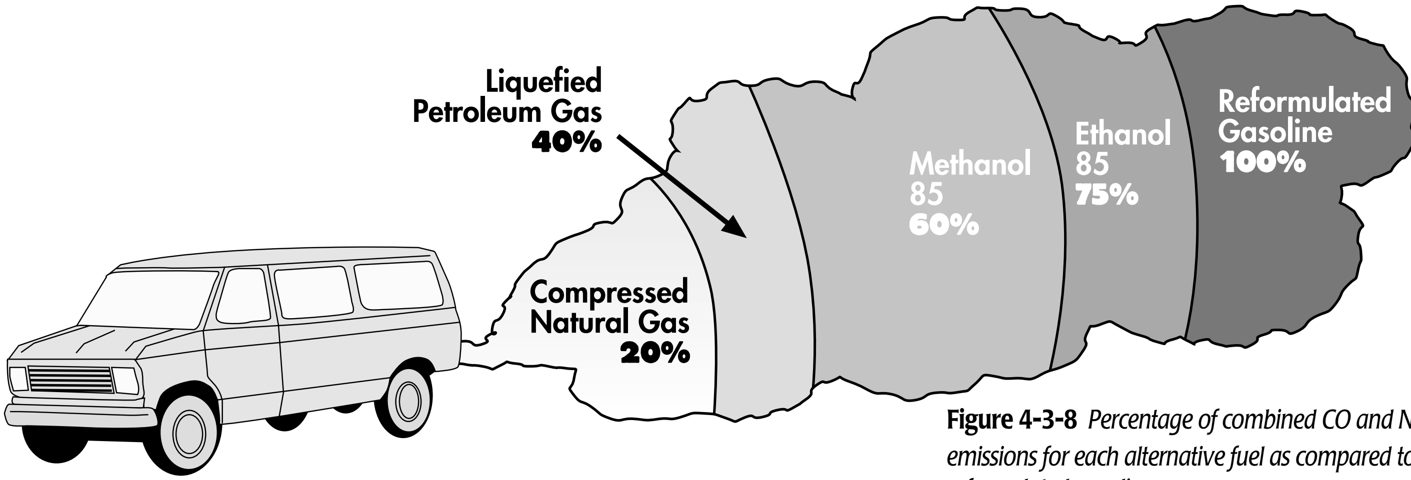


Figure 4-3-8 *Percentage of combined CO and NO_X emissions for each alternative fuel as compared to reformulated gasoline.*
Source: U.S. Department of Energy

Pursuing alternative fuels programs will slow the increase in carbon dioxide and the effects of greenhouse gases. However, some scientists fear that corrective measures will not take place fast enough. These scientists believe it is important to look at all forms of alternative energy to limit global warming as soon as possible.

Global Climate Change Resource List

www.epa.gov/globalwarming/index.html
U.S. Environmental Protection Agency
General information and a children's site for younger audiences. Covers weather, climate systems, climate change over time, climate studies, policy options and games that can be used as an assessment tool.

http://www.gcrio.org/ask-doctor.html
U.S. Global Change Research Information Office
A reference service for researchers, students, educators, and the general public seeking information on global environmental change.

http://daphne.palomar.edu/evolve
Palomar College, San Marcos, California
Tutorial on theories of evolution; addresses pre-Darwinian theory, Darwin and natural selection, and evidence. Includes maps, sound and graphics; practice quizzes follow each section with automatic feedback.

http://aa.usno.navy.mil/AA/faq/docs/seasons_orbit.html
United States Naval Observatory
"The Seasons and the Earth's Orbit – Milankovitch Cycles" explains how the long-term cycles of the earth's orbit have the potential to affect climate.

http://www.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/warming.htm
National Aeronautics and Space Administration
History of global warming research from Arrhenius in 1896 to current models. Includes an investigation of the greenhouse effect with the General Circulation Model developed by NASA's Goddard Institute for Space Studies.

http://vector.cshl.org/dnaftb
Josiah Macy, Jr., Foundation
"DNA From the Beginning" is an animated primer on the basics of DNA, genes, and heredity.